PAV-89-04

Rout and Seal Cracks in Flexible Pavement – A Cost-effective Preventive Maintenance Procedure

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Ministry of Transportation

Research and Development Branch

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Rout and Seal Cracks in Flexible Pavement
– A Cost-effective Preventive Maintenance Procedure

Author(s):	G.J. Chong, Pavements and Roadway Office, Research and Development Branch
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	The Ministry of Transportation of Ontario conducted a comprehensive study on the feasibility of a rout and seal treatment of cracks in flexible pavement as a preventive maintenance procedure. The objectives of this study were to ascertain the cost-effectiveness of this rout and seal procedure based on the successful treatment of the distress, the resultant extension of pavement service life, and the optimum timing for application of this treatment to achieve maximum cost benefit. Implemented in 1986 across the province of Ontario, the study ensures complete coverage of different climatic and environmental conditions. Monitoring of the treatment performance and pavement condition has been completed for a period including three winters. From the data, it has been established that certain rout configurations are more effective in different regions in the province; the rout and seal treatment effectively delays or even stops progressive distress deterioration; the treatment is essential to achieve maximum cost benefit, with the optimum time being from the 3rd to 5th years for initial treatment, and the 8th to 9th years for follow-up treatment.
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G.J. Chong
Research Engineer
Research and Development Branch

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For additional copies, contact:
The Editor, Technical Publications
Room 320, Central Building
1201 Wilson Avenue
Downsview, Ontario
Canada M3M 1J8

Telephone: (416) 235-3480
Fax: (416) 235-4872
CNCP Dialcom Electronic Mail: 23:MIN006

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1/ Introduction

The Ministry of Transportation (MTO) employs two maintenance treatments for cracks on flexible pavement and composite pavement; one, the traditional spray patching with emulsified asphalt and sand or stone chips and, beginning in the mid-seventies, the method commonly know as Rout and Seal. [1]

Of these two treatments, time has demonstrated that sealing with emulsified asphalt is not only ineffective but can create undesirable side-effects [2,3]. On the other hand, rout and seal has shown success in effective maintenance of cracks, although the question of how cost-effective this particular maintenance treatment is, has not been answered [4,5].

In 1981, a small experimental study was initiated by MTO Pavements and Roadway Office and the Ottawa District Maintenance Office. It has provided very significant, though limited, cost-effectiveness data [2,4,5]. In 1986, the Ministry's Highway Operations and Maintenance Division initiated a comprehensive study program on rout and seal treatment of cracks as a preventive maintenance procedure with the Pavements and Roadway Office as the appointed co-ordinator. The scope of this later study is an extension of the 1981 study but is now province-wide to ensure complete coverage of the different climatic and environmental conditions that exist in Ontario [4,5].

2/ Provincial Program

The proposed program's course of action is as follows:

1. Pavement sections selected for study should be from age groups of less than 3 years, 4 to 6 years, and 7 to 9 years. Each group should have a minimum of 2 test sections.

2. The test section should have a minimum of 5 subsections of 150 mm each.

3. The subsections should be laid out with the control section located between the 4 remaining sections of rout and seal treatment.

4. Two subsections should have rout size of 40 x 10 mm.

5. Two subsections should have rout sizes of 19 x 19 mm, if pavement is located in Districts 5, 7, 8, 9, 10 and upward; and 12 x 12 mm if pavement is located in Districts 1, 2, 3, 4 and 6.

6. Low modulus polymer sealants of Hydrotech 6165 and Tremco THC 200 are to be used in Districts 5, 7, 8, 9, 10 and upward; and Hydrotech 6165 and standard Hydrotech 6160 sealants are to be used in Districts 1, 2, 3, 4 and 6.

7. A standard crew with standardized equipment from the Ministry's Ottawa District should be used to minimize installation variables.

8. The study will be co-ordinated and monitored by the Pavements and Roadway Office of the Research and Development Branch of MTO.

2.1/ Program Objectives

The program must determine the following:

1. Definitions and standards for rout and seal operational specifications for both in-house and contract work in terms of:

   a. Equipment.

   b. Methodology.

   c. Materials for different climatic and environmental conditions.

   d. Rout size for different climatic and environmental conditions.

2. Effectiveness of treatment.

3. Extension of pavement service life.

4. Importance of timing of treatment for cost-effectiveness.

5. Consequences of deferred treatment.

2.2/ Test Section Selection

A total of 37 test sections were selected from the 3 different age groups and from 4 different regions of the province:

1. **Age Group**

    a. 1-3 years - 10 sections

    b. 4-6 years - 13 sections

    c. 7-9 years - 14 sections

2. **Regions**

    a. Northern Region - 6 sections

    b. Eastern Region - 9 sections

    c. Central Region - 2 sections

    d. Southwestern Region - 20 sections

2.3/ Procedures

The procedures for rout and seal treatment experiment are as follows:

2.3.1/ Monitoring

First a condition survey is carried out using the "Condition Survey of Pavement Surface Form" shown in Figure 1. The same form will be used for subsequent monitoring during the successive winters (month(s) of January and/or February).

Pavement sections under study must be identified by completing the following:

1. Highway No. - Number of highway.

2. Location - Proximity to the nearest town or city, major highway interchanges, or any other prominent landmarks.

3. Date of Survey - Date the condition survey is taken.

4. Section - Test section number based on predetermined number provided. For example, if test section number is 20, then section number should be 20-1, or 20-2, or 20-3, or 20-4. The control section where no rout and seal work is to be carried out will be labelled "Control".

5. Rout size - Size of rout designated and used on the section. That is, either 12 x 12 mm, 19 x 19 mm, or 40 x 10 mm.

6. Material - The sealant material used for sealing of the rout crack. Brand name and type designation must be given. Example: Hydrotech 6165.

7. Crack Mapping - The "Form" is set up for a 200 metre 2-lane section in 10 m increments. The cracks should be drawn as accurately as possible on the Form.

8. Transverse Crack (Total Length) - The total length of transverse cracks in the section measured to the nearest metre with a measuring wheel (sealed and unsealed).

9. Longitudinal Crack (Total Length) - The total length of cracks other than transverse cracks in the section to be measured to the nearest metre with a measuring wheel (sealed and unsealed).

10. Total Length of Cracks - Combined length of all cracks in metres from items 8 and 9.

11. Transverse Crack Cupping/Lipping - If present, check either slight, moderate, or severe, based on the general condition of the transverse cracks with cupping or lipping.

12. Crack Spalling - If present, check either few, frequent, or extensive, for all cracks in the section. The percentage is based on the number of cracks that have spalled.

13. Crack Opening - This is for unsealed cracks only. Check the appropriate square for transverse crack openings and for longitudinal crack openings based on the general condition of the section.

14. Sealant Bond Failure - This is for sealed sections only. Check the appropriate square for bond failure of the sealant. Failure includes one-side debonding, both-side debonding, and sealant splitting. The percentage is based on proportion of total length of all sealed cracks in the section.

2.3.2/ Roughness Measurement

Roughness (Ride Quality) Measurement to be made by MTO Pavement Design and Evaluation Office with the Mays Meter at the original position; measurement to be made in summer.

Repeat measurement at 5 years after or at termination of the study; measurement to be made in the same time frame as original measurement.

2.3.3/ Treatment Operation

Crew Complement

Foreman/woman	1
Router Operator	2
Hot Lance Operator	1
Kettle Operator	1
Tow Vehicle Operator	1
Total	6

Safety personnel to be supplied by local patrol(s) where work is located.

Equipment Complement

Router	2
Hot Lance	1
Kettle	2
Tow Vehicle	2
Crew Cab 1 Ton	1
Total	8

Safety personnel to be supplied by local patrol(s) where work is located.

Work Procedures

1. Both kettles to be used at the same time, each specifically for one designated sealant material.
2. One router set up permanently for 40 x 10 mm.
3. One router set up for 12 x 12 mm or 19 x 19 mm, depending on locality of work.
4. Hot lance used just ahead of kettle.

3/ Summary of Field Operations

The field operation began in June, 1986, and was completed in September, 1986, a month behind schedule due to a record-breaking rainy summer, the worst experienced by the Province in the last 50 years.

Test sections No.5 and No. 24, were deleted because major maintenance was performed on No. 5 prior to rout and seal treatment, and section No. 24 exhibited massive multiple cracking with spalling, making it impractical to use for the study purpose. One test section, No. 36, was simplified to a 40 x 10 mm test section and Hydrotech sealed under a post-construction arrangement for a rehabilitation contract.

Although low modulus polymer sealant TREMCO THC200 was ordered, the manufacturer supplied in error the standard TREMCO THC205.

A number of test sections were also sealed with Hydrotech 6160 because not enough TREMCO was made available. These were sections 31 to 34, inclusive, in District 8.

Between 1986 and 1989, a number of test sections were also lost due to either major maintenance or rehabilitation. The casualties were sections 16 and 31.

4/ 1986 to 1989 Monitoring Results

Monitoring of the rout and seal test sections and their corresponding control sections was conducted between January and March of 1987, 1988 and 1989. All three winters experienced a similar pattern; below average snowfalls, and prolonged periods of above average temperatures with short durations of very intense cold days.

4.1/ Equipment and Methodolgy

The equipment and work procedures developed by the Pavements and Roadway Office and the Ottawa District Maintenance Office employed for the study proved to be highly efficient and productive in successfully water-proofing the cracks in the pavement surface.

Details were published fully in 1988 in Research Report PAV-87-01 "Improved Preventive Maintenance: Sealing Cracks in Flexible Pavements in Cold Regions", presented at the Transportation Research Board Annual Meeting, Washington, D.C. in 1988 [5].

4.2/ Materials and Rout Configuration

After three winters of monitoring, the performance evaluation based on bond failure occurrences gives the following ranking orders :

1. **Materials Performance** (Figure 2)
   - TREMCO 205
   - HYDROTECH 6160
   - HYDROTECH 6165

2. **Material Matched With Rout Configuration** (Figure 3)
   - 12 x 12 mm with TREMCO 205
   - 12 x 12 mm with HYDROTECH 6165
   - 40 x 10 mm with TREMCO 205 or HYDROTECH 6160 / 12 x 12 mm with HYDROTECH 6160
   - 40 x 10 mm with HYDROTECH 6165
   - 19 x 19 mm with TREMCO 205
   - 19 x 19 mm with HYDROTECH 6160
   - 19 x 19 mm with HYDROTECH 6165

3. **Rout Configuration (All Ontario)** (Figure 4)
   - 12 x 12 mm/40 x 10 mm
   - 19 x 19 mm

4. **Rout Configuration (Cold Region)** (Figure 5)
   - 40 x 10 mm
   - 19 x 19 mm

5. **Rout Configuration (Milder Region)** (Figure 6)
   - equal for 12 x 12 mm and 40 x 10 mm

4.3/ Crack Development

Crack Development is assessed based on the value of Crack Factor: the total linear length in metres of transverse cracks and longitudinal cracks on the pavement surface divided by the total surface area in square metres of the pavement section. That is,

$$Fc = \frac{Lc}{A} \times 100$$

Figure 7 shows the crack factor for various pavement age, from 1 year to 12 years. It appears that crack development begins from year one of the pavement service life and increases steadily until year six. Crack development becomes static until the eleventh year, when the increase becomes quite dramatic.

Figure 8 shows crack factor for transverse and longitudinal cracks separately for various pavements from 1 year to 12 years old. It appears that transverse cracks develop fully in the first year of the pavement service life and remain quite static until the eleventh year, when a sharp increase begins to take place.

Figures 7 and 8 also show that the initial crack factor is generated nearly solely by transverse cracks, and that increases between year one and year six are from longitudinal crack development.

Figures 7 and 8 also show that pavement with very low crack factor will remain static over its service life in crack development.

4.4/ Crack Deterioration (Lipping/Cupping)

Crack deterioration is assessed based on evaluation of deformation in the form of lipping or cupping. Figure 9 shows the different rates of deterioration for rout and seal treated cracks and non-sealed cracks from the control sections after 3 winters of service life. The rout and seal cracks remain static in performance, whereas the cracks in the control sections show significant increase in lipping/cupping deterioration after 3 winters.

5/ Discussion of Results

5.1/ Cost-effectiveness of Maintenance Treatment

The cost-effectiveness of a maintenance treatment depends on:

1. How the treatment changes the existing condition; that is, how effectively it corrects the existing distress.
2. How well the treatment effectively delays the distress's deterioration process, thereby extending the pavement service life.
3. Whether there is a particular condition or time during the progression of the cracking distress when appropriate maintenance can be most effective.

The information needed to establish cost-effectiveness must therefore quantify:

1. The effectiveness of treatment: that is,
   a. performance of sealant materials over time;
   b. performance of various rout width and depth sizes over time to establish the most efficient rout configuration.
2. The extension of pavement service life:
   a. retarding of additional crack development;
   b. delaying the deterioration process of the existing distress.
3. The influence of time: the point in the pavement's life cycle at which the treatment is most cost-effectively applied.

5.2/ Effectiveness of Treatment

5.2.1/ Material Performance

All three materials are approved and included in the Ministry Designated Sources List. Performance based on the criteria of bond failure indicates that TREMCO 205 and Hydrotech 6160, which both conform to ASTM D-1190, are similar and better than the low stiffness modulus Hydrotech 6165, which conforms to ASTM D-3405 (Figure 2).

This evidence appears to contradict the previous assumption that the low modulus materials will perform better in a harsher climate than the standard D-1190 formulation.

However, it should be noted that overall performance for all three sealant materials is exceptionally good since after 3 winters of service life, less than 10% of the sealant suffered "extensive" bond failure rating.

5.2.2/ Material/Rout Configuration Performance

All three sealant materials are matched with rout configurations of 12 x 12 mm and 40 x 10 mm for the southern part of the province and 19 x 19 mm and 40 x 10 mm for central, eastern, and northern areas.

Performance based on the criteria of bond failures indicates that regardless of materials, rout configuration of 19 x 19 mm is the poorest performer. There is virtually no difference in performance between 12 x 12 mm and 40 x 10 mm in southern Ontario, where the climatic condition is considered milder (Figures 3, 4, 5 and 6).

The results definitely reinforce the previous assumption that rout configuration of 19 x 19 mm for asphalt concrete pavement is the least desirable and should be discarded. For uniformity, rout configuration of 40 x 10 mm should be the standard province wide. For southern districts of 1, 2, 3, 4 and 6, 12 x 12 mm rout size can be used as the optional standard, especially for urban expressways.

5.3/ Extension of Pavement Service Life

5.3.1/ Crack Development

Evaluation of crack development during the pavement service life based on the criteria of crack factor shows that cracking increases from the first to the sixth year when it becomes more or less static until the tenth year. From the eleventh year onward, crack development appears to accelerate (Figure 7).

But the most interesting aspect is that transverse cracking developed almost immediately from year one to its full potential and thereafter remained fairly static until the tenth year. From the eleventh year onward, it appears to again accelerate. In addition, cracks other than transverse appear to begin their development in the second year of pavement service life and reach a peak in the sixth year, which accounts for the trend of increasing crack factor from year one to six (Figure 8).

Rout and seal treatment of cracks does not appear to have a great deal of influence on crack development, since there is no discernable trend in crack development between the sealed test sections and the unsealed control sections.

5.3.2/ Crack Deterioration

The criteria used to determine crack deterioration is the degree of deformation at the transverse crack, commonly known as either lipping or cupping. Treatment is considered to be effective when it either retards or stops the deformation process thus extending pavement service life. An increase in deformation results in increased roughness in the pavement surface and reduced serviceability.

Figure 9 shows quite dramatically the static condition of the rout and seal test sections after 3 winters of the treatment's service life. The unsealed control sections indicate a marked increase in the severity of lipping/cupping distress.

5.4/ Timing

The data on crack development, indicates that rout and seal treatment should be applied between the third and fifth year for maximum cost-benefit, (Figures 7 and 8). For pavement with very low crack factor, say less than 2.0 by the fourth year, there is no benefit to rout and seal cracks as the crack factor will remain static and low, (Figures 7 and 8).

A second rout and seal treatment can also be very cost-effective in prolonging or extending pavement surface life if it is carried out at the eighth or ninth year before crack development begins to accelerate.

6/ Mini-experimental Study

In 1981, a small scale study was launched by the Pavements and Roadway Office and the Ottawa District Maintenance Office to look into the consequence of sealing pavement cracks with rout and seal treatment versus deferred maintenance [2,4,5].

A section of Highway 17 near Ottawa was selected as it was originally constructed in 1965 with 115 mm (4 1/2 inches) of Hot-mix asphalt, and rehabilitated in 1979 with 65 mm (2 1/2 inches) of Hot-mix asphalt because of extensive cracking. In 1981, 2 years after resurfacing, extensive transverse cracks reappeared and the pavement was routed and sealed as a preventive maintenance measure. Part of this pavement was used for the mini-experimental study.

In 1985, an investigation was made of the deferred maintenance control section and the rout and seal test sections. Results proved that rout and seal treatment has prevented secondary crack development on the sealed cracks and also stopped or retarded internal deterioration, which is reflected on the surface as cupping deformation [5].

In 1989, as part of the Winter monitoring program, a performance evaluation was made of the experimental test sections. The performance data are presented in Table I.

6.1/ Material Performance

Hydrotech 6160 and Meadow 164R had been approved as sealant materials at the same time. The third material which had just been placed in the marketplace, was the Shell Cariphalte, a low stiffness modulus polymer material which Shell Canada hoped would be accepted by the Ministry on the Designated Sources List. (Shell Canada has now discontinued the manufacturing and sale of this product.)

After eight winters of service life, the sealants are still effective in their designed function, which is waterproofing the pavement surface. This includes the Meadow 164R which has the worst performance record for bond failure and was subsequently withdrawn from the market by its

manufacturer. Figure 10 shows a typical rout and seal crack using Hydrotech 6160; Figure 11, the Shell Cariphalte; and Figure 12, the Meadow 164R.

6.2/ Pavement Performance

The sealed test sections, Meadow 164R included, are definitely in better condition than the control section, (see Table I). The sealed cracks remained sealed with little secondary crack development. New crack development for sealed sections is also less than in the control section which in 1989 is estimated as approximately 30% more than in 1981.

There is no spalling with the sealed cracks, whereas spalling has occurred in numerous unsealed cracks in the control section, (Figure 13).

New crack development after the sealing in 1981 has had no maintenance in the sealed test sections or in the control section. These unsealed cracks have now progressed to openings of as much as, 19 to 25 mm. It will be beneficial to have a follow-up rout and seal treatment in the eighth or ninth year to extend the pavement service life before accelerated deterioration takes place.

7/ Summary

Rout and seal treatment is designed to seal asphalt concrete pavement cracks to prevent water from entering and damaging the pavement structure. It is important for pavements in cold areas because of the combination of low temperature induced crack opening and the winter maintenance practice of snow and ice removal with salt.

This experimental study evaluating the effectiveness of rout and seal treatment and its cost-benefit has achieved very good results which lead to the following conclusions:

1. The equipment and methodology presently employed by the Ministry is efficient and highly successful and should be the specified standard.

2. All three approved materials on the Ministry Designated Sourcess List perform satisfactorily whether they are formulated to meet ASTM D-1190 or D-3405.

3. Standard rout configuration for the Province of Ontario should be 40 x 10 mm.

4. Rout configuration for southern Ontario (District 1, 2, 3, 4 and 6) should have 12 x 12 mm as the optional choice. The 12 x 12 mm will present an even neater appearance, less material usage than 40 x 10 mm and will be especially suitable for urban expressway systems.

5. Rout and seal treatment will either stop or retard the deformation commonly known as lipping/cupping, which is detrimental to pavement serviceability and, therefore pavement service life.

6. The initial rout and seal treatment must be performed between the third and the fifth year of the pavement service life to achieve maximum cost-effectiveness.

7. The second rout and seal treatment,which is a follow-up operation should be performed between the eighth and the ninth year of the pavement service life to extract the maximum benefit of the initial treatment in extending pavement service life.

8. For pavement with initial low crack factor (2.0 or less) at the fourth year of pavement service life, rout and seal treatment has doubtful benefit.

9. Deferred maintenance particularly on transverse cracks is NOT an acceptable engineering or economical option.

8/ Recommendations

Three winters of monitoring have now been completed. But it is essential that monitoring continue until the sealant reaches extensive failure or at minimum, for an additional two years.

It is also recommended that the Pavement Design and Evaluation Section of the Highway Design Office be the body designated to continue further monitoring of this project.

Acknowledgement

The author wishes to state clearly that the views expressed herein are not necessarily the position of the Ministry.

The author also wishes to thank all those who took part in this study: the Ottawa District Rout and Seal Crew headed by Foreman, Mr. Mike Houle; Mr. J. Armstrong, Ottawa District Maintenance Supervisor; Mr. Fred Jewer, Maintenance Branch; Mr. M.G. Stott (retired) and Mr. T. Khan of Pavements and Roadway Office who were responsible for all winter monitoring and data analysis. Their contributions are invaluable and greatly appreciated.

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SECTION NO.	CHAINAGE (km)	MATERIAL	ROUT	SEALANT BOND CONDITION
1	0 - 1.0	Hydrotech	19 mm	<10% bond failure, about 5 cm sealant missing from <10% of crack <15% new cracks developed, Average crack width 13-19 mm
2	1.0 - 2.0	Control		<30% new cracks developed Most transverse crack width 13-19 mm, some 19-25 mm Most longitudinal crack width 6-13 mm, some 13-19 mm
3	2.0 - 2.5	Shell	19 mm	No bond failure, no sealant missing <10% new cracks developed Average transverse crack width 6-13 mm, CL crack >25 mm
4	2.5 - 3.0	Shell	10 mm	No bond failure, no sealant missing <10% new cracks developed Average crack width 6-13 mm, some longitudinal cracks 19-25 mm
5	3.0 - 4.0	Hydrotech	10 mm	<10% bond failure, no sealant missing <10% new cracks developed Average crack width 6-13 mm, some longitudinal cracks 19-25 mm
6	4.0 - 4.5	Meadows	10 mm	>50% bond failure, about 5 cm sealant missing from most cracks <15% new cracks developed Average crack width 6-13 mm, some longitudinal cracks 19-25 mm
7	4.5 - 5.0	Meadows	19 mm	>50% bond failure, about 5 cm sealant missing from 50% of cracks <15% new cracks developed Average crack width 6-13 mm, some longitudinal cracks >25 mm
8A	7.4 - 7.9	Meadows	Flat	>40% bond failure, about 5 cm sealant missing from 25% of cracks <15% new cracks developed Average crack width 6-13 mm, some longitudinal cracks >25 mm
8B	7.9 - 8.4	Meadows	Bead	>40% bond failure, about 5 cm sealant missing from 10% of cracks <15% new cracks developed Average crack width 6-13 mm, some longitudinal cracks >25 mm
8C	7.9 - 8.4	Hydrotech	Bead	<10% bond failure, no sealant missing <15% new cracks developed Average crack width 6-13 mm, some longitudinal cracks >25 mm
8D	7.4 - 7.9	Hydrotech	Flat	<10% bond failure, no sealant missing <15% new cracks developed Average crack width 6-13 mm, some longitudinal cracks >25 mm

Table 1/ Mini-Experimental Study. Highway 17, Ottawa District

MINISTRY OF TRANSPORTATION OF ONTARIO
RESEARCH AND DEVELOPMENT BRANCH
CONDITION SURVEY OF PAVEMENT SURFACE

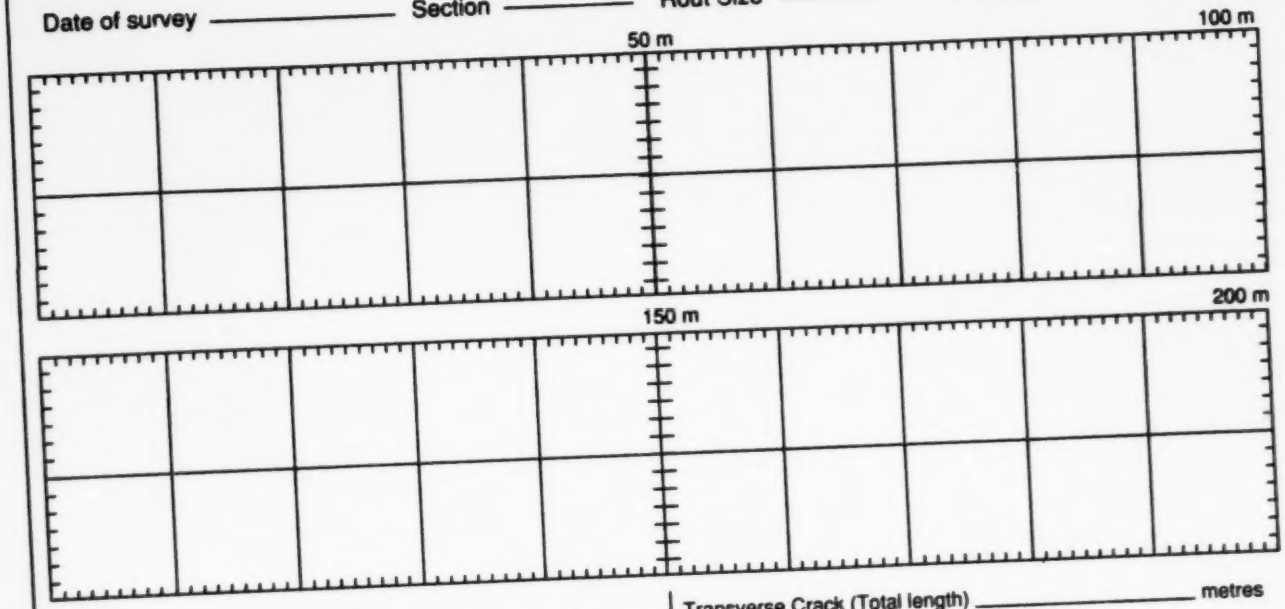
SHEET NUMBER ____ OF ____

SCALE
1 div. = 1 m

HWY. NO. _____

LOCATION: _____

Date of survey _____ Section _____ Rout Size _____ Material _____



Remarks _____

Transverse Crack (Total length) _____ metres

Longitudinal Crack (Total length) _____ metres

Total; Length of Cracks _____ metres

Transverse Crack Cupping/Lipping

	yes	no
	☐	☐
Slight	☐ ⩽ 5 mm	
Moderate	☐ 6-12 mm	
Severe	☐ > 13 mm	

Crack Spalling

	yes	no
	☐	☐
Few	☐ < 10 %	
Frequent	☐ 11-50 %	
Extensive	☐ > 50 %	

Crack Opening

Trans.	Longit.	
☐	☐	⩽ 2 mm
☐	☐	6 - 13 mm
☐	☐	13 - 19 mm
☐	☐	19 - 25 mm
☐	☐	> 25 mm

Sealant Bond Failure

Few	☐ ⩽ 10 %
Frequent	☐ 11-50 %
Extensive	☐ > 50 %
Complete	☐ 100 %

Figure 1/ Condition Survey of Pavement Surface Form

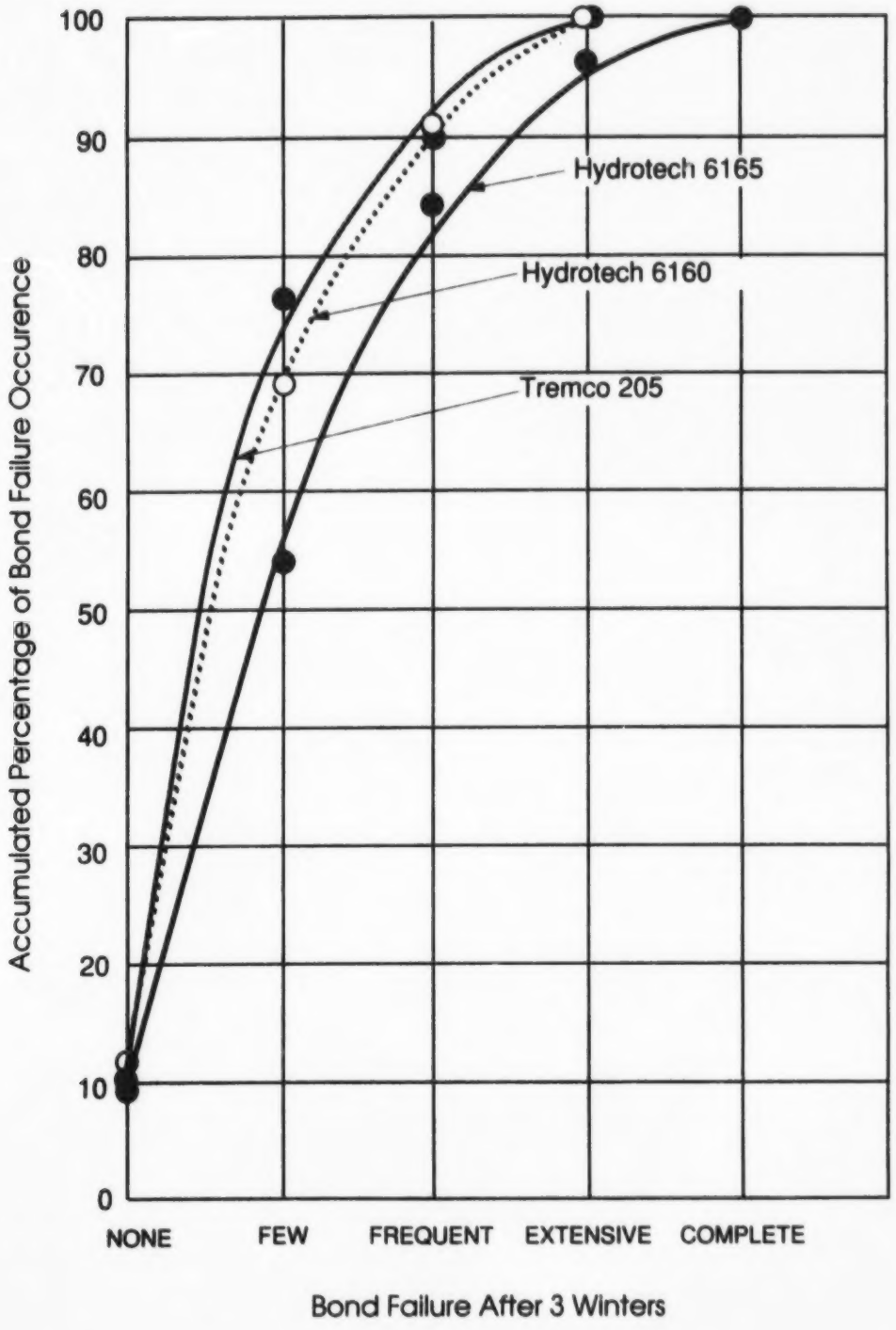


Figure 2/ Ranking of Materials on Bond Performance

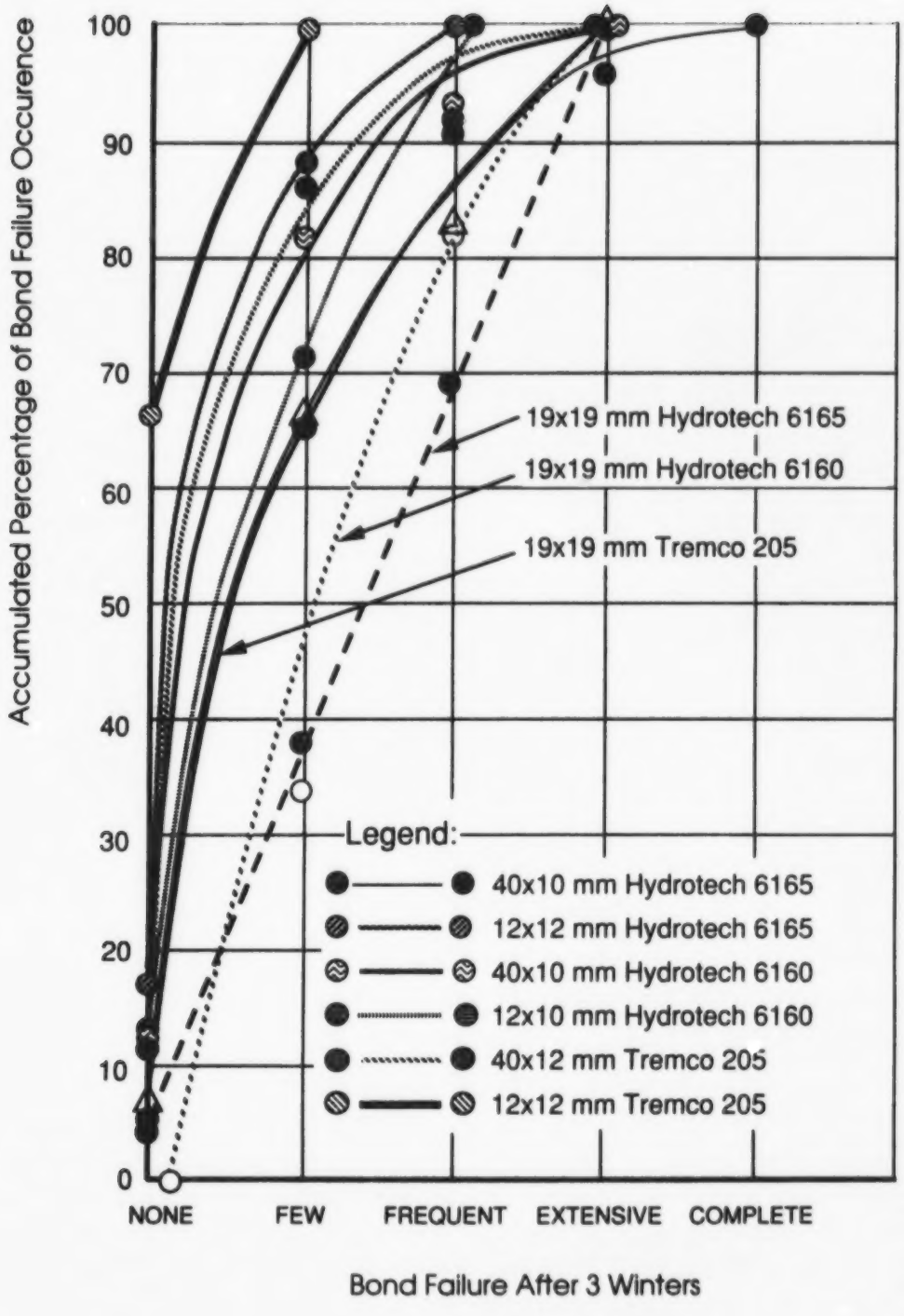


Figure 3/ Ranking of Material/Rout Configuration on Bond Performance

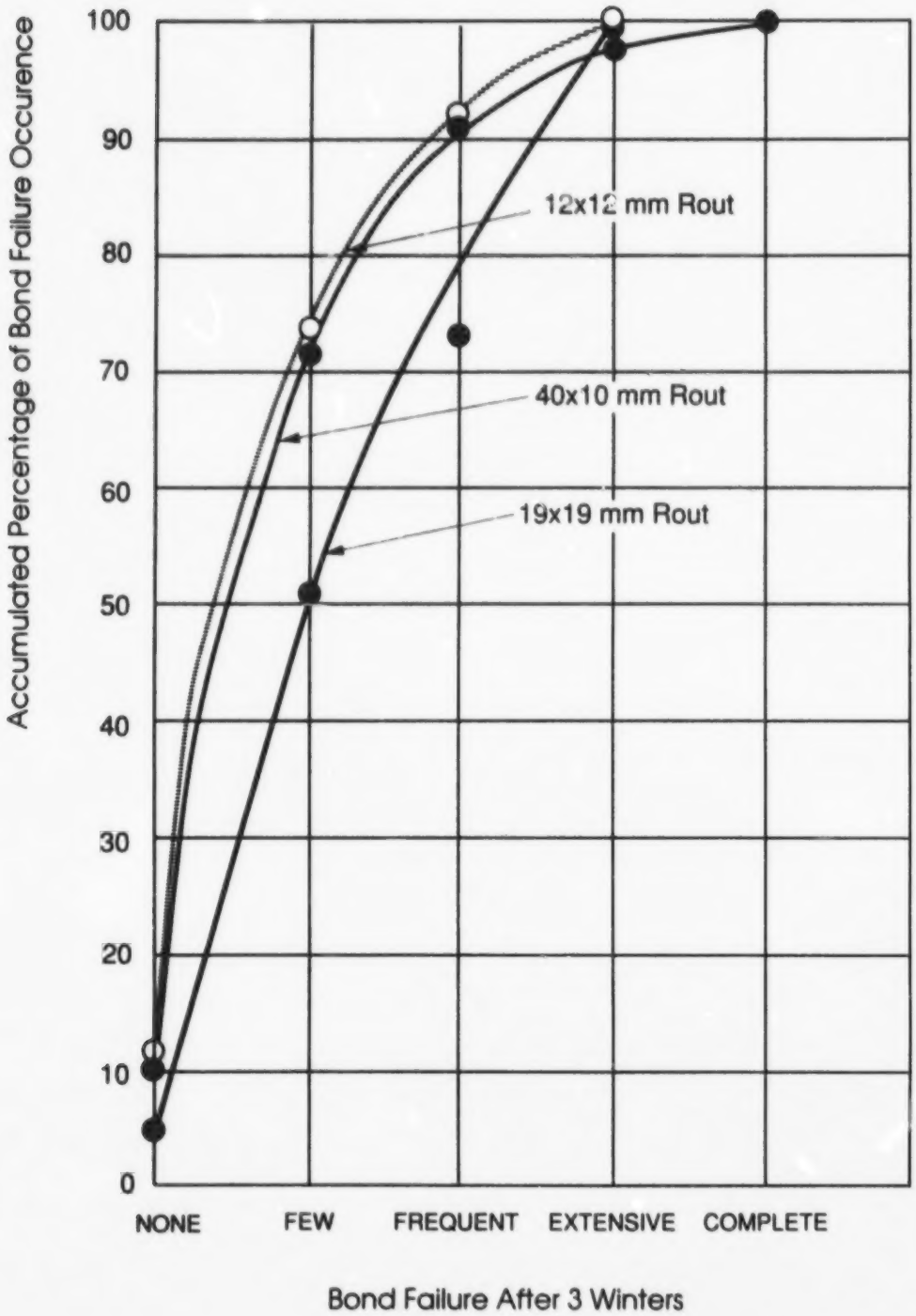


Figure 4/ Ranking of Rout Configuration on Bond Performance (All Ontario)

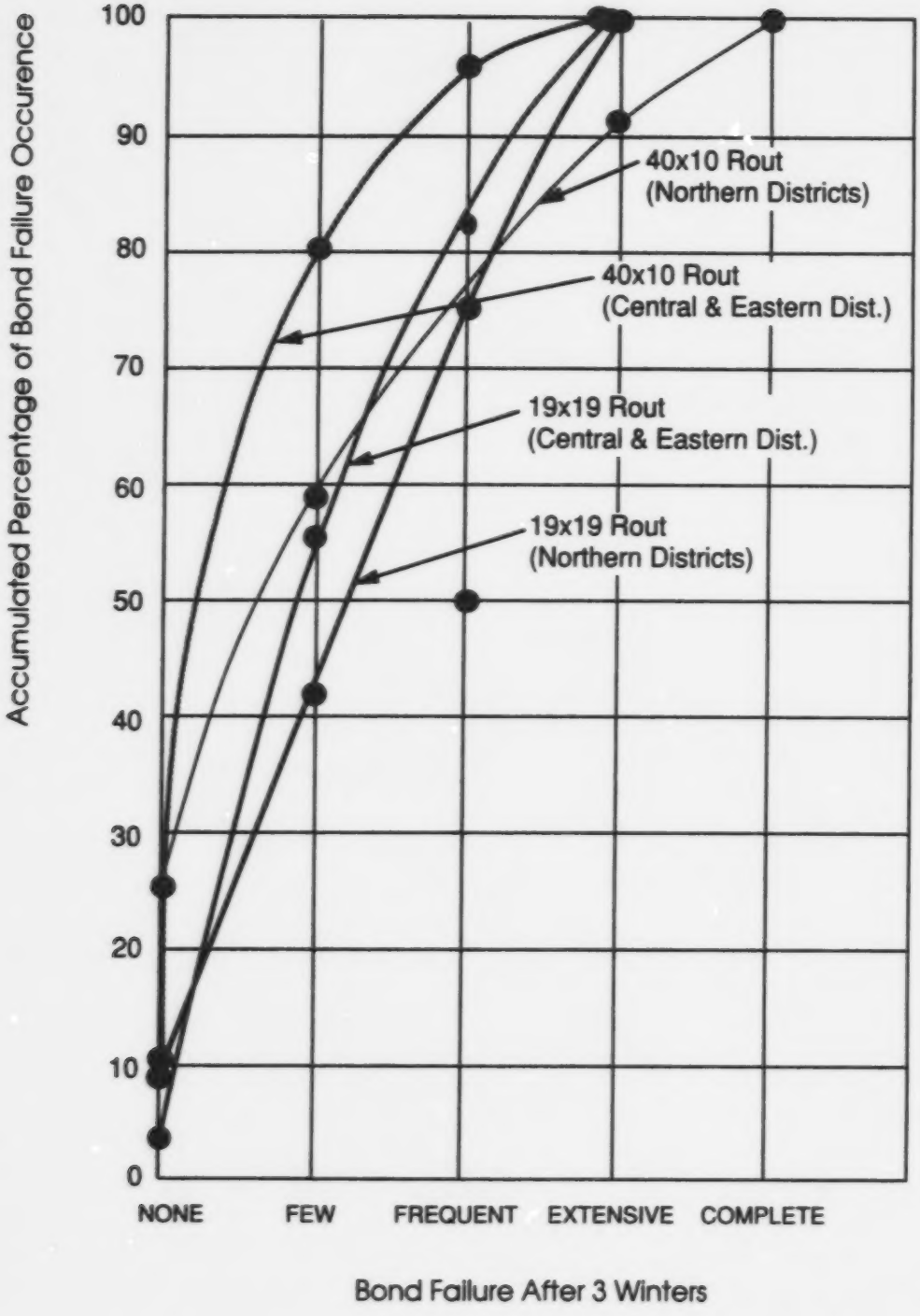


Figure 5/ Ranking of Rout Configuration on Bond Performance
(Central, Eastern, Northern Districts)

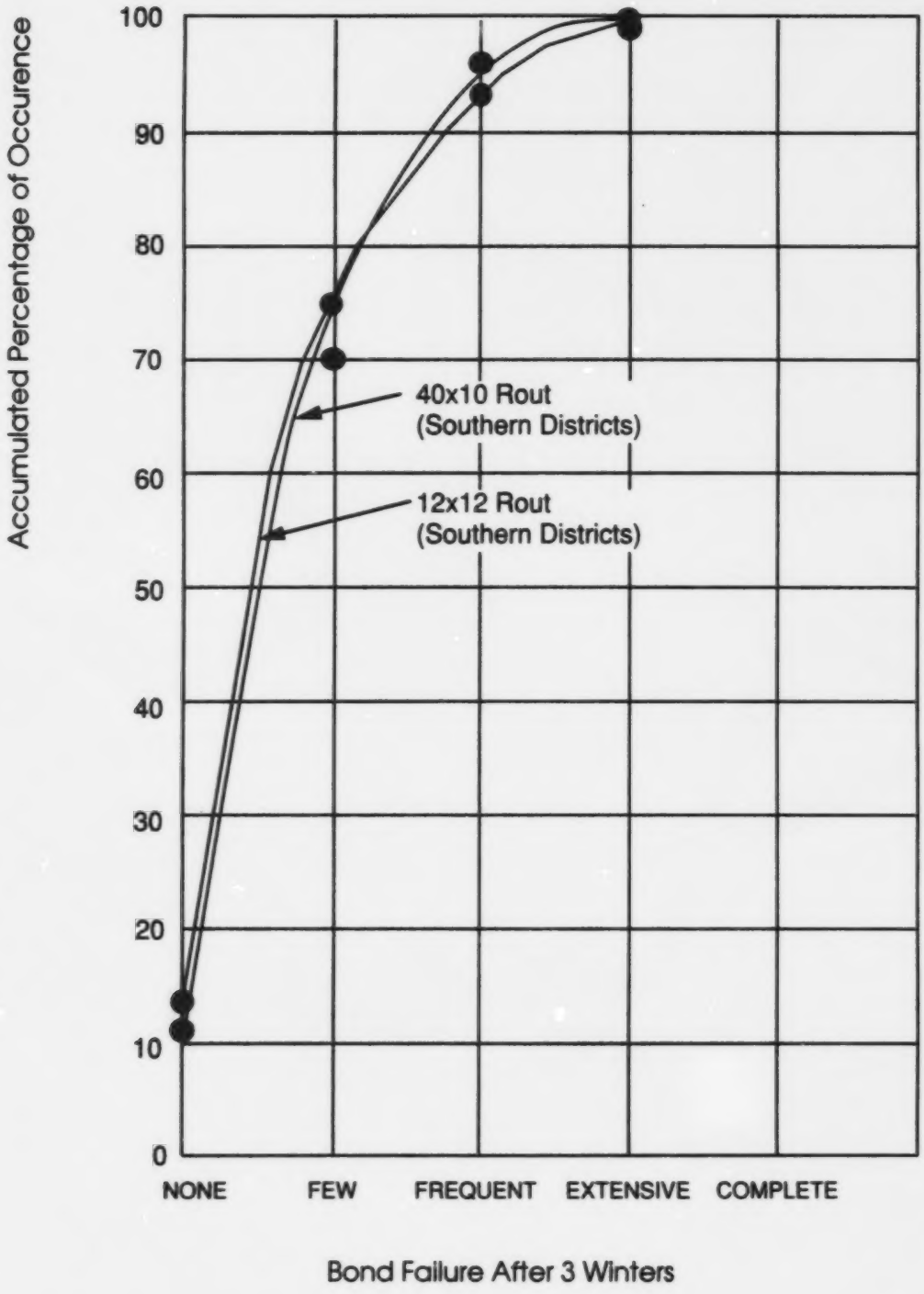


Figure 6/ Ranking of Rout Configuration on Bond Performance
(Southern Districts only)

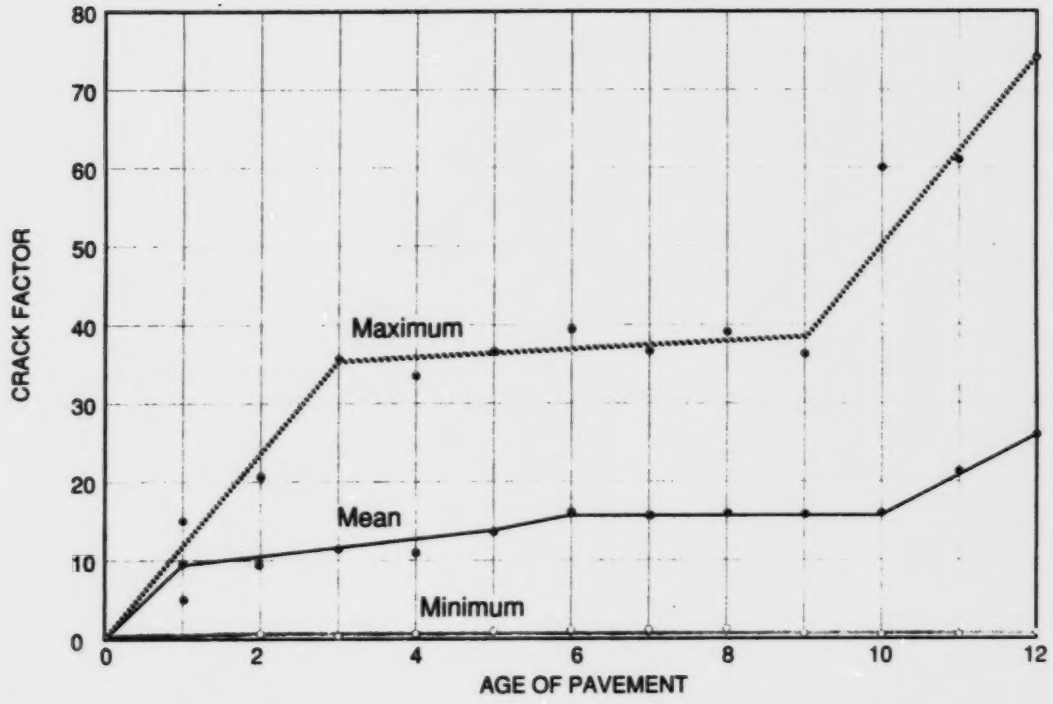


Figure 7/ Crack factor for Transverse and Longitudinal Crackings Combined

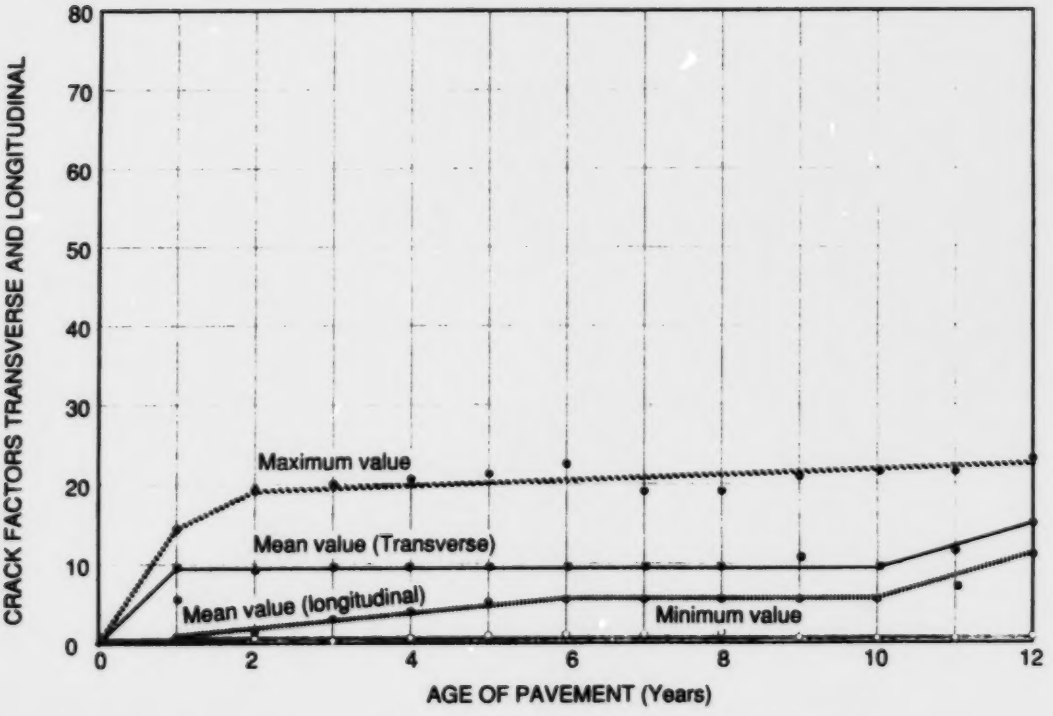


Figure 8/ Crack factors for Transverse and Longitudinal Crackings Only

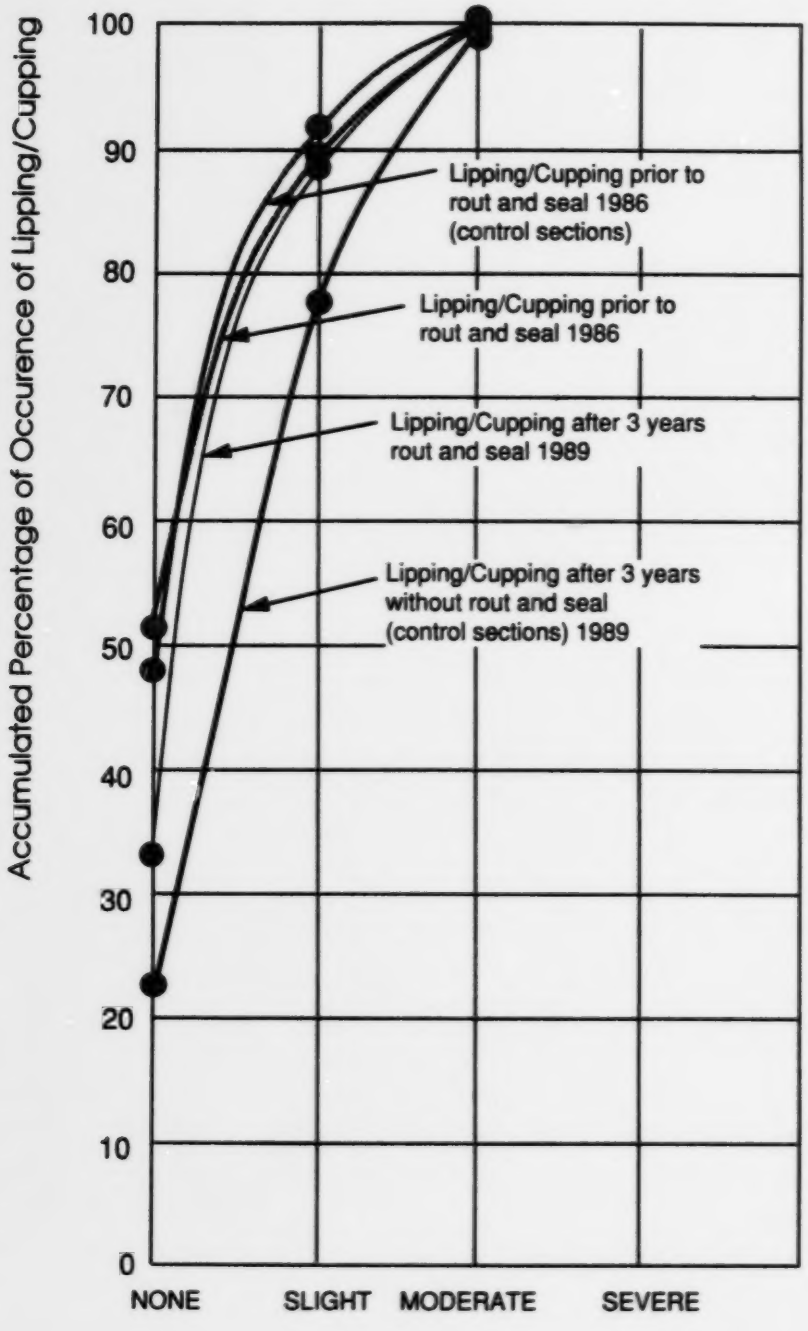


Figure 9/ Crack Deterioration after 3 Winters

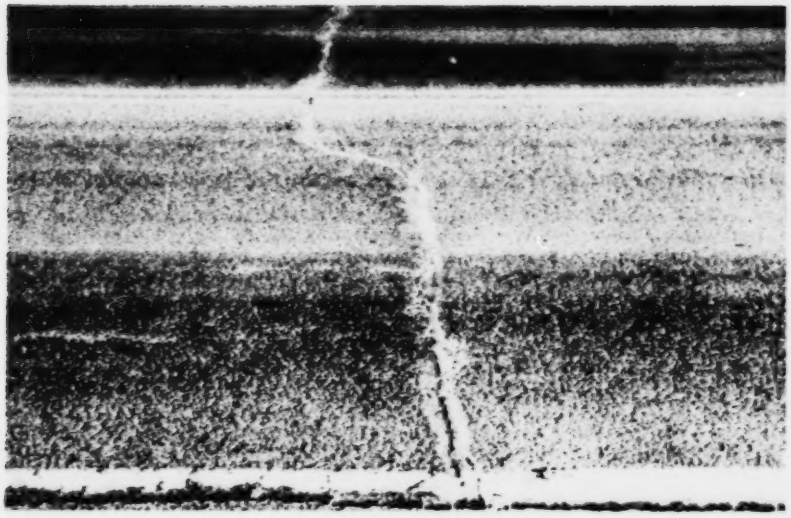


Figure 10/ 19 x19 mm Rout and Seal with Hydrotech 6160
Test Section 1, 1981 (Photo February, 1989)

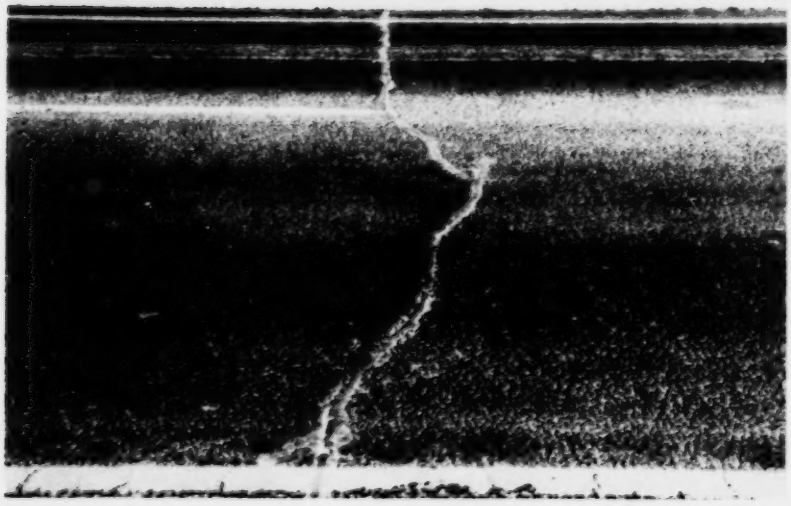


Figure 11/ 19 x 19 mm Rout and Seal with Shell Cariphalte
Test Section 3, 1981 (Photo February, 1989)

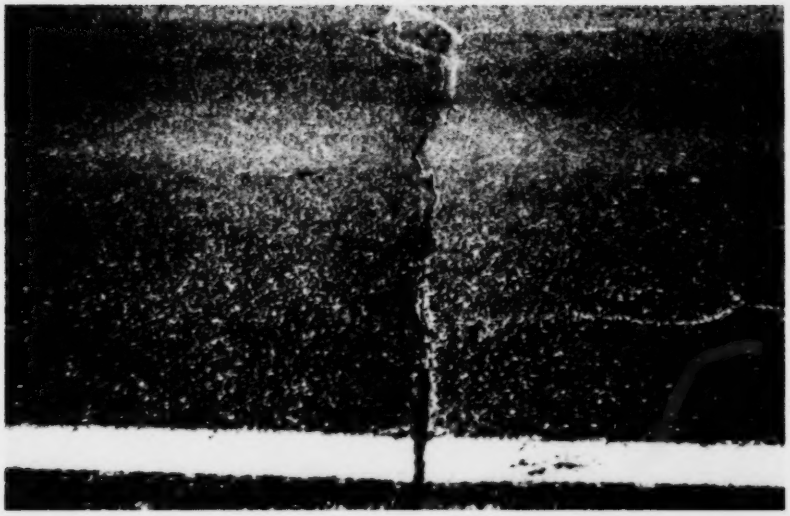


Figure 12/ 19 x19 mm Rout and Seal with Meadow 164 R
Test Section 7, 1981 (Photo February, 1989)

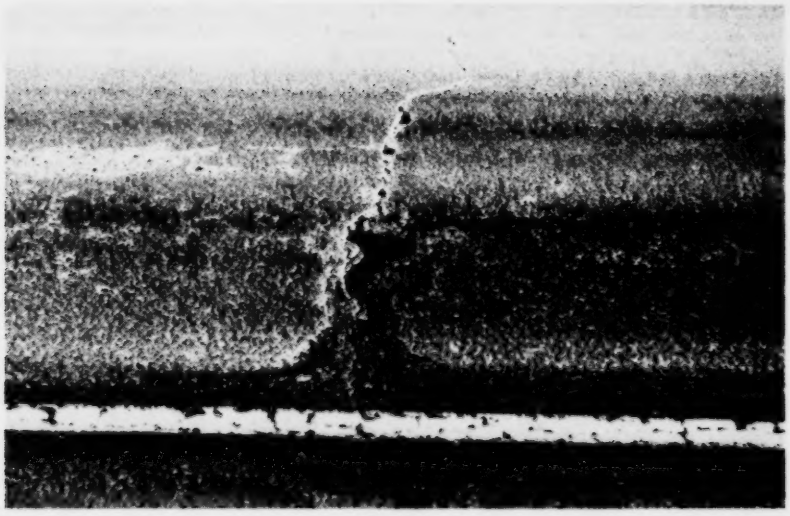


Figure 13/ No Maintenance
Test Section 2, Control, 1981 (Photo February,1989)